Topsy on the Palm Pilot

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Abstract

Since some years, the new trendy in computer market seems to grow towards the offer of more functionality such as WAP, date-book, bank-transactions and address book for portable systems like cellular phones or palm-tops. Normally, such systems are based on a monolithic operating system, specially designed for an unique architecture; thus until now the efforts to led to the creation of OS for multiple architecture brought to unsatisfiable results.
The Computer Engineering and Networks Laboratory (TIK) of the Swiss Federal Institute of Technologies has developed a new OS: Topsy. Originally designed for teaching purpose of practical exercises related to the courses, its simplicity, readability, transparency and hardware independence, led quickly to implementations for different platforms. Moreover, Topsy is available under the Gnu Public Licence (GPL). Due to all its properties, Topsy is then a very good candidate to be introduced in this new emerging technologies.
Leader on the market of PDAs is actually the Palm Inc. with its Palm Pilot; moreover emulators for this platform are free available on Internet. These preconditions lead to the idea of an implementation of Topsy for the Palm Pilot. The GNU utilities (C-compiler, assembler, linker) and the GNU/Linux platform can be used for the port in order to keep all the work available under the GPL.
This diploma work presents the porting of Topsy's hardware abstraction layer (HAL) for the Palm Pilot, using the xcopilot emulator. This functioning basis offers the possibility of further development of this OS on the Palm platform in a very quick and easy way.

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Chapter 1

Introduction

During the last years, the classical idea of the PC as a multi-purpose device is declining. Thanks to the new technologies in miniaturisation, the power of a mid/low-range PC is available for portable systems like cellular phones or palm-tops. Thus, more functionality can be embedded into these devices, an example can be the tools available in cellular phones or the growth of the palm-tops market.
Technologies are expected to merge: The phone, the fax, the calculator, the camera, the tape recorder, the walk-man, etc. might develop into one little machine, a true personal digital assistant (PDA).

Nowadays, several companies are fighting to get the best position in this market. For example Microsoft with its WinCE [1] is trying to offer the look and feel of Windows on a large variety of devices, and Palm Inc. [2] a very simple and compact OS. Unfortunately WinCE suffers many problems related to the heterogeneity of the hardware and software incompatibilities, while PalmOS [3] is available only for MC68328-based [4] handhelds. Until now, no one seems to be able to offer a stable, portable, simple and well-designed operating system for PDAs.

These characteristics can be found in Topsy [5], an operating system developed by the Computer Engineering and Networks Laboratory (TIK) of the Swiss Federal Institute of Technologies. It is released under the Gnu Public License (GPL) and offers many interesting features: Topsy is very thin (compiled is about 100Kbytes), is portable, the code is highly readable because of its teaching-purpose nature (Topsy stands for **T**eachable **OP**erating **SY**stem) and it is not over-featured.

The aim of this work is to present the port of this OS for the Palm Pilot platform, chosen because of its success in the PDA market and because of its very simple and clean hardware design: Today Palm Inc. is the leader in market (PalmOS powers over 75% of the worldwide personal companion market [6]) with its very popular series of handhelds based on MC68328 and MC68EZ328 DragonBall processors [7]. The offered operating system, is used on other similar devices produced by Handspring [8], Sony [9], IBM [10], Kyocera [11], etc. [12].
Topsy has been already implemented for an IP-Phone [13] that uses a processor similar to the one present in the Palm platform, belonging to the Motorola 68000 family [14]. However, the architecture of the PDA used for this work is far more complex because of differences in the processor itself, the presence of a liquid crystal device, serials ports, etc. Moreover, the compiler utilised (GNU C-compiler: GCC [15]) is rather different in handling the assembler code: Most of the machine-dependant code has to be rewritten from scratch.

Starting with the first model of Palm, the Pilot1000 produced in 1996 by U.S. Robotics (Tab. 2.1), the Open Source community was amazed by this new product of the technology. The Palm became quick a “must-have” and was not surprising that after a short time an emulator, named xcopilot and based on the code of the Unix Amiga Emulator (UAE [16]), was implemented.

Nowadays, xcopilot is not more supported by Palm Inc. because of a new environment for developing PalmOS-specific applications: The **P**alm **OS E**mulator (Pose) [17]. Fortunately, thanks to the porting of Linux (μCLinux project) to the Palm [18], the product is still supported by the Open Source community, and new features specially designed for the development of embedded operating systems will be added in the near future.
The comfort of using an emulator running on the same environment of the creation of the Topsy code, lead to the decision to not use the Motorola development-board [19].

This work will present the port of Topsy to the Palm models based on the MC68328 DragonBall processor. The xcopilot emulator was used as device. All the tools utilized for this purpose and the results produced, are released under the GPL. A version for MC68EZ328 processor (PalmV*x*) is also available, but not tested.

Chapter 2

Material and Methods

In this chapter, the tools used to port the Topsy's Hardware Abstraction Layer (HAL) to the Palm are presented.
The host machine used for the work is an Intel-Pentium based PC and the operating system is GNU/Linux (SuSE distribution version 7.0 [20]). The compiler utilised is the GNU C-compiler (GCC) and the Palm emulator is xcopilot.

2.1 Palm

Date	Models
Mar 1996	Pilot1000, Pilot5000
Mar 1997	PalmPilot Professional, PalmPilot Personal Edition
Mar 1998	Palm III
Feb 1999	Palm III*x*, PalmV
May 1999	PalmVII
Jul 1999	PalmIII*e*
Feb 2000	PalmIII*c*
Aug 2000	PalmVII*x*, Palm m100

Table 2.1: Brief history of models of the PalmPilot. In May 1997, 3Com purchased U.S.Robotics and got Palm Computing Inc. as a bonus

The latest two models of Palm Pilot produced by the 3COM are based on two very similar processors: The Motorola MC68328 [4] and the Motorola MC68EZ328 [7]. The latter is also present in the PalmV, while the PalmIII models use the other processor.

The emulator used during this work, xcopilot 0.6.6, is based on the MC68328 processor, while the newest Pose [17] uses the MC68EZ328. Unfortunately Pose is not a real emulator of the whole hardware, it can be considered as system for developing and testing applications specifically designed for PalmOS. This is the reason why the no anymore supported xcopilot has been chosen by the μCLinux[1] team and for this work.

[1] Pronounced "you-see-linux"

2.1.1 MC68328 architecture

The purpose of this section is to give an overview of the architecture of the MC68328 in order to provide the basics for the next chapters.

The MC68328 DragonBall combines an MC68EC000 [21] processor with peripheral modules like liquid crystal display (LCD) controller, UART and infra-red communication support and serial peripheral interface.

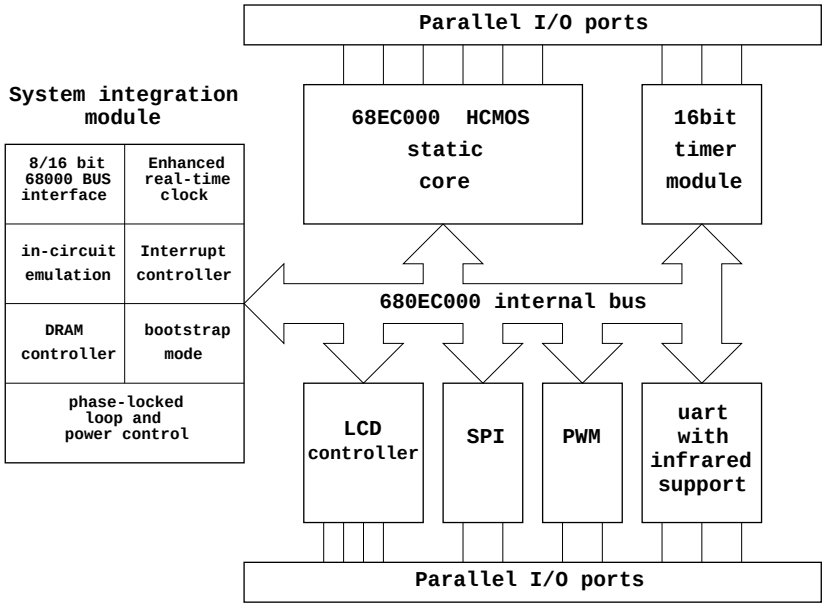


Figure 2.1: The MC68328 Block Diagram.

The MC68EC000 core

The MC68EC000 core in the MC68328 is an updated implementation of the MC68000 [14] 32-bit microprocessor architecture.
The main features of the core are:

- Low power, static HCMOS implementation.
- 32bit address bus and 16bit data bus.
- Sixteen 32bit data and address registers.
- 56 instruction types.
- 14 addressing modes and five main data types.
- Seven priority levels for interrupt control.
- Big Endian data format.
- Supervisor- (privileged) and user-mode.

The M68EC000 programming model consists of two register groups: User and supervisor. User programs executing in the user mode only use the registers in the user group. System software executing in the supervisor mode can access all registers and use the control registers in the supervisor group to perform supervisor functions.
The 16 general-purpose registers are divided into two categories: The first eight registers (`%d7-%d0`) are data registers that are used for byte (8bit), word (16bit) and long-word (32bit) operations. The next seven registers (`%a6-%a0`) and the stack pointer (`%a7`/`%sp`) can function as base address registers or index registers for long and long-word operations. Register `%a7` is used as a hardware stack pointer during stacking for subroutines calls and exception handling.
In supervisor mode, the upper byte of the status register (`%sr`) can also be programmed.

Fig. 2.2 shows the value of the bits composing the status register.

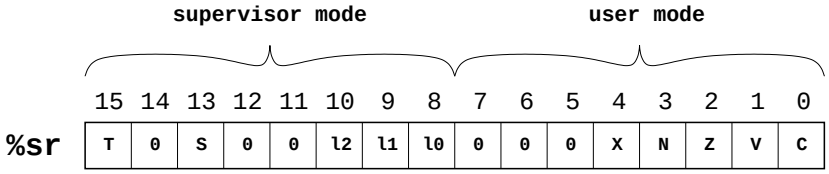


Figure 2.2: The status register (`%sr`) contains the interrupt mask with seven available levels (l2, l1, l0), as well as extend (X), negative (N), zero (Z), overflow (V) and carry (C) condition code. The T bit indicates when the processor is in trace mode and the S bit indicates when it is in supervisor (S=1) or user mode (S=0).

The stack on MC68EC000

The stack on the MC68EC000 grows from the high memory to the low memory. By using the convention to visualise the stack with the address `0x00000000` on the top and the address `0xffffffff` on the bottom, the analogy of “pushing” data on the stack and to “pop” them is simple to keep in mind.

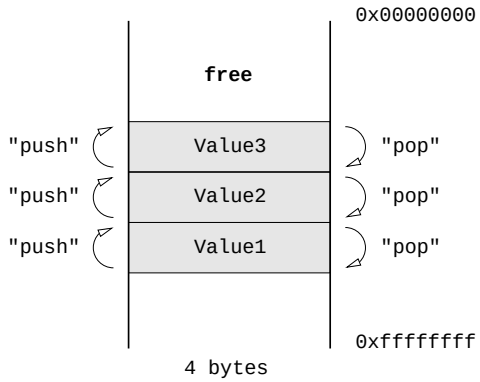


Figure 2.3: The stack pointer is automatically increased each time a value is pushed on the stack and decreased for each “pop” operation.

Fig. 2.3 gives an example of the stack after three push-operations. To restore the original situation, three pop-operations are required.

To implement stack growth, `-(%sp)` (pre decrement) is used to push data and `(%sp)+` (post incre-

ment) to pop from the stack. After each operation, the stack pointer register points to the top item on the stack. The example of Fig. 2.3, is the result of three push-operations and three pop-operations (Tab. 2.1.1).

```
move.l Value1, -(%sp)  /*  Push Value1 on the stack     */
move.l Value2, -(%sp)  /*  Push Value2 on the stack     */
move.l Value3, -(%sp)  /*  Push Value3 on the stack     */
                       /*  Value3 available at (%sp)    */
                       /*  Value2 available at -4(%sp)  */
                       /*  Value1 available at -8(%sp)  */
move.l (%sp)+, %d3     /*  Pop Value3 from the stack    */
move.l (%sp)+, %d2     /*  Pop Value2 from the stack    */
move.l (%sp)+, %d1     /*  Pop Value1 from the stack    */
                       /*  Value3 available in %d3      */
                       /*  Value2 available in %d2      */
                       /*  Value1 available in %d1      */
```

The interrupt handling

The MC68328 offers 256 interrupts. This means the vector number is an 8bit digit (**I**nterrupt **V**ector **R**egister, `IVR`). The vector number will be multiplied by 4 to obtain the address of the exception vector. The exception vector is the memory location from which the processor fetches the address of the routine that will handle the exception. For simplicity, the value of IVR can be seen as an index into an array of addresses of functions. The table of exception vector occupies 1Kbyte of memory (each address is 4Byte long: 256*4=1024) and it is starting at `0x00000000` (Fig. 2.4).

Interrupts are processed in the following sequence:

1. The interrupt controller collects interrupt events, prioritises them and presents the highest to the core processor (if there are no higher interrupts pending).
2. The core processor responds to the interrupt request by executing an interrupt acknowledge bus cycle after the completion of the current instruction.
3. The interrupt controller recognises the interrupt acknowledge cycle and places the interrupt vector for that interrupt request onto the core processor bus.
4. The core processor reads the vector and address of the interrupt handler in the exception vector table and executes code at that address.

More informations about the use of the interrupts in Topsy can be found in 3.3.1.

LCD controller

The LCD controller is used to display data on an LCD module. It fetches display data from system memory through periodic DMA transfer cycles. It supports monochrome LCD module with a maximum of sixteen gray levels.

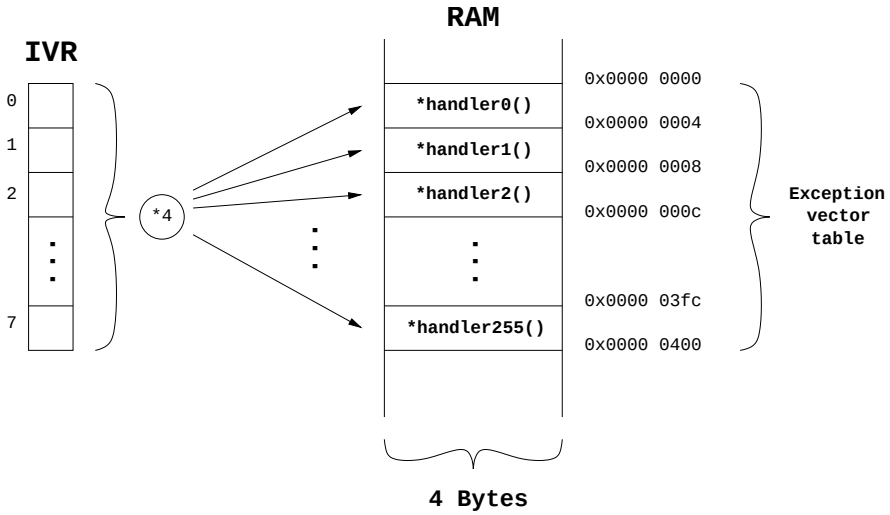


Figure 2.4: The value of Interrupt Vector Register ("IVR") is multiplied by 4 to obtain the address of an exception vector. The exception vector is the memory location from which the processor fetches the address of the routine that will handle the exception (`*handler0()`, ..., `*handler255()`).

The screen width and height of the LCD panel are software programmable using the LXMAX (width) and LYMAX (height) registers. The LCD controller starts scanning the display memory at the location pointed by the LCD screen starting address register (LSSA). The maximum page width and height are specified by the LCD virtual page width (LVPW) and height (LPVH) registers: By changing the value of the LSSA register, a screen-sized window can be vertically or horizontally scrolled anywhere inside the virtual page boundaries (Fig. 2.5).

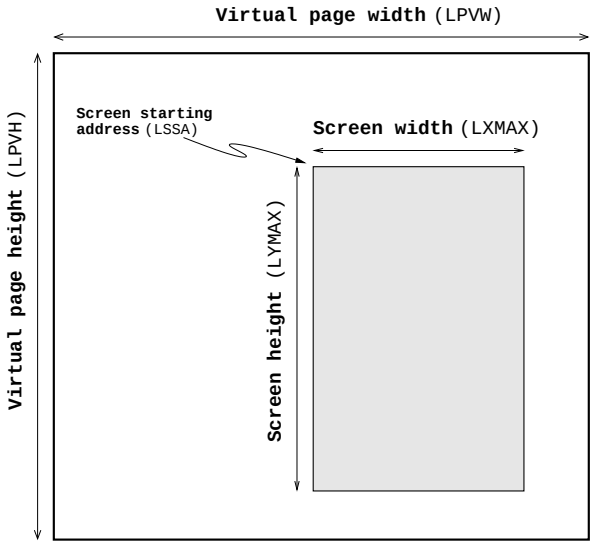


Figure 2.5: LCD screen format.

2.1.2 The xcopilot emulator

xcopilot is an emulator of 3Com Palm that runs on Unix systems under X11 [22]. For some years, it has not been supported anymore because of Pose. Unfortunately, the official home page [2] doesn't seem to be available, but the latest version of the emulator (0.6.6, 6 September 1998) can still be downloaded from the home page of the μCLinux project [23]. A patched version which fixes a few bugs when doing shared memory on the Linux-Slackware distribution is also available [24].
xcopilot doesn't seem to work properly with the newest linux-kernel: The emulator doesn't even start with the version 2.4.1; with linux-kernel version 2.2.17 it functions properly.

Debugging

xcopilot offers two methods for debugging applications. One method uses gdb but is available only under PalmOS because of the need of the "gdb panel" application. The other is turned on by using the `-debug` command-line option: It starts a third process that acts as a debug server attached to the TCP-port number 2000. Unfortunately, even this possibility seems to be unavailable in the current version of xcopilot: Investigations with the netstat utility don't reveal the presence of this listening port.

The method used in this work to debug the Topsy kernel is based on the memory dump generated by xcopilot when quitting: The file `pilot.ram` present in the Topsy main directory is the image of the 4Mb of RAM between `0x1000000` and `0x10400000`. The utility used to analyse the binary file is `hexdump`: Because of the endianess differences between Intel and Motorola architecture, the `hex` utility used for the logo leads to incorrect values.
Because of the success of μCLinux, some patches have been applied to xcopilot. The most interesting (but still not 100% working) gives the possibility to put breakpoints in the code and use gdb (`m68k-coff-gdb`) as debugging tool. At this time, only a pre-alpha patched version of xcopilot is available [25]. For more information about the build of xcopilot and how to add the debugging features in Topsy, follow the instruction of the file `README.gdbstub` included in the emulator's package. For an overview about debugging methods, refer to Sec. 4.2.1.

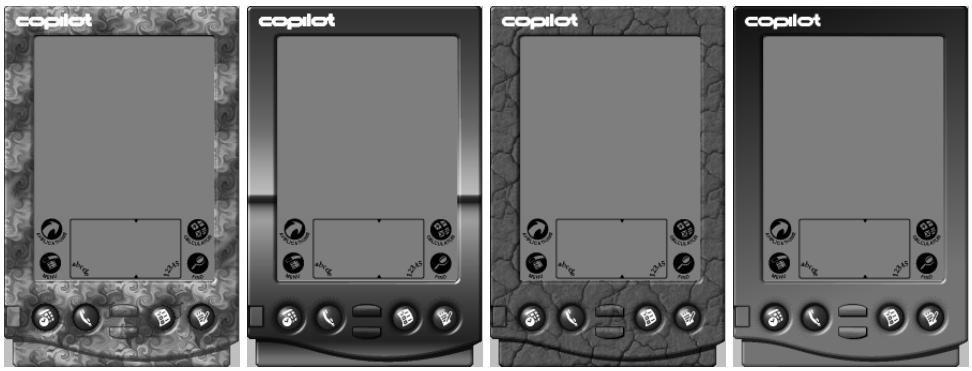
"Skins"

There is the possibility to personalise the look of xcopilot by changing its "skin". Skins are graphical files in XPixmap (`.xpm`) format that can replace the original one (Fig. 2.6). The new graphical interface of the emulator can be substituted using any draw program, for example, The Gimp. To change the look of **xcopilot**, simply copy the new skin with name `case.xpm` in the emulator's main directory, remove the `display.o` file and compile. Nevertheless, the apparency of the emulator is not important for its correct functioning.

2.2 The GNU C suite

The spirit of this work is to release the port of Topsy under the GPL. For coherence with this idea, the materials used have to be available with the same licence.
The Gnu C-compiler (GCC) is one of the most famous products of the Free Software Foundation and

[2] `http://xcopilot.cuspy.com`



(a) Hippie **(b)** Horizon **(c)** Marple **(d)** Stylish

Figure 2.6: Four "skins" available for xcopilot. Other examples are available at `http://www.the-labs.com/PDA/`

produces code for various architectures, including the MC68000[3].

This section explains how to build a cross-compiler, in this case that means a C-compiler, assembler, linker, debugger, libraries and utilities that run on an Intel platform ("host") but are used to generate code for the m68k ("target"). More informations can be found on the HOWTO [26].

2.2.1 The software

First of all, a compiler has to be already available on the host machine in order to build the needed tools, and, moreover it must include support for m68k code. GCC contains m68k support starting from version 2.7.1; in this work the version used is 2.95.2.

In this work, the following tools (available in every mirror of the GNU site [27]) were used:

- Assembler, linker, utilities: binutils-2.10.
- Compiler: gcc-2.95.2.
- Debugger: gdb-5.0.
- Library: glibc-2.2 or newlib-1.8.2.

GLIBC is generally better for larger (unix-based) systems, while **newlib** is more appropriate for embedded applications. Thus, the latter was chosen. An alternative to **GLIBC** can be the **diet libc** [28], but unfortunately this library is only static. Another library, expecially designed for embedded systems, is **uClibc** [29]. Unfortunately, at this moment it is available only for Intel architecture, a port for m68k architecture is expected.

2.2.2 Compilation and installation

Creating and installing a cross compiler on a Linux-box is quite simple. First of all, the downloaded archives [30] have to be unpacked into a temporary directory, for example in `/tmp`. Then the system

[3]For coherency with the GNU documentation, from now the term "m68k" will be used to identify the Motorola MC68000 processor

has to be configured, the tools have to be compiled and installed. Just change directory to `/tmp` and follow the steps below: The cross-compiler is installed into `/usr/local/cross-gcc`:

1. ***Configure the system:***

   Set the destination directory:
   `prefix=/usr/local/cross-gcc`
   Set target system:
   `target=m68k-coff`
   Set the directories created by unpacking sources:
   ```
   gccdir=gcc-2.95.2
   newlibdir=newlib-1.8.2
   gdbdir=gdb-5.0
   ```
   Create the destination directory:
   `mkdir -p $prefix`

2. ***Compile and install binutils:***

   ```
   mkdir -p build$binutilsdir
   cd build$binutilsdir
   ../binutilsdir/configure --target=$target --prefix=$prefix -v
   make all install
   cd ..
   ```

3. ***Add executables to path*** (they'll be needed later):

   ```
   PATH=$PATH:$prefix/bin
   ```

4. ***Add symbolic links to newlib into GCC source:***

   ```
   cd $gccdir
   ln -s ../$newlibdir/newlib newlib
   ln -s ../$newlibdir/libgloss libgloss
   cd ..
   ```

5. ***Compile and install gcc and newlib:***

   ```
   mkdir -p build$gccdir
   cd build$gccdir
   ../$gccdir/configure --target=$target --prefix=$prefix \
       --with-newlib --enable-languages -v
   make all install
   cd ..
   ```

6. ***Compile and install gdb:***

   ```
   mkdir -p build$gdbdir
   cd build$gdbdir
   ../$gdbdir/configure --target=$target --prefix=$prefix -v
   make all install
   cd ..
   ```

The cross-compiler will not substitute the existing utilities because of the prefix "m68k-coff-". For example the objcopy utility for m68k objects is named m68k-coff-objcopy. To include the `$prefix` directory, the `$PATH` env-variable has to be updated.

In order to save disk space, it would be a good idea to recursively delete the contents of the `build` subdirectories at the end of the process.
This configuration works for embedded systems only because of **newlib**. Problems can arise while building a cross-compiler for Solaris: The header files for Solaris aren't provided by **newlib**.

A good resource for cross-compiling informations is the frequently asked questions (FAQ) document [31].

2.2.3 GCC

In order to better understand the assembler routines described later in this work, some knowledge about how GCC passes parameters to functions ("function-calling convention") and about inline-assembly is needed.

Function-calling convention

The GNU C Compiler pushes on the stack the values to pass to functions and uses the register `%d0` for return-values. The parameters are pushed from left to right: That means that, using 4bytes-long parameters, the first one is located at `4(%sp)`, the second at `8(%sp)`, and so on (Fig. 2.7). At `(%sp)` is present the program counter (`%pc`) of the calling routine.

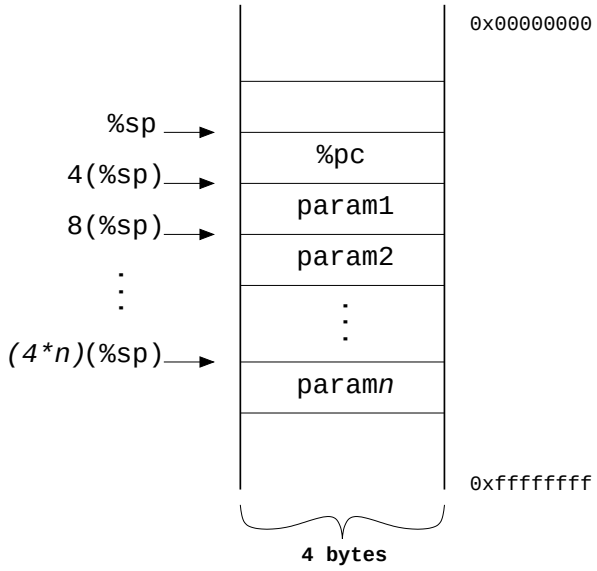


Figure 2.7: Example of stack layout by GCC function-calling convention, after the BSR (**B**ranch **S**ub**R**outine) instruction. The function example is `f(param1, param2,..., paramn)` and all parameters have length 4Bytes.

Inline assembly

With the GNU C Compiler it is possible to mix assembler in C code. This can result to be very comfortable especially for very short routines. GCC uses the assembler "**as**" (**m68k-coff-as**) as a backend, the syntax used is known with the name "AT&T" syntax. For more informations, refer to [32].

2.3 Topsy

Topsy is a small operating system which has been designed by the Computer Engineering and Network Laboratory (TIK) of the Swiss Federal Institute of Technologies in Zürich (ETHZ). This OS was designed for teaching purposes (Topsy stands for **T**eachable **OP**erating **SY**stem) in practical exercises related to the courses, and its simplicity, readability, transparency and hardware independence, led quickly to implementations for different platforms.

Characteristic:

Topsy is a multi-threaded operating system; that means all threads of a specific process (kernel or user) are running in one address space and may share global memory. Thus, the memory is divided into two address spaces: One for user threads and the other one for the threads that belong to the kernel.
Topsy is modular, that means the kernel contains three main modules reflecting the basic tasks performed by the OS: The memory manager, the thread manager and the I/O subsystem. The communication system is the same as in user threads, based on sending and receiving messages (message-passing), this provides a quick response to interrupts and synchronisation between modules.

For an overview on the structure of the Topsy Operating System, please refer to [5].

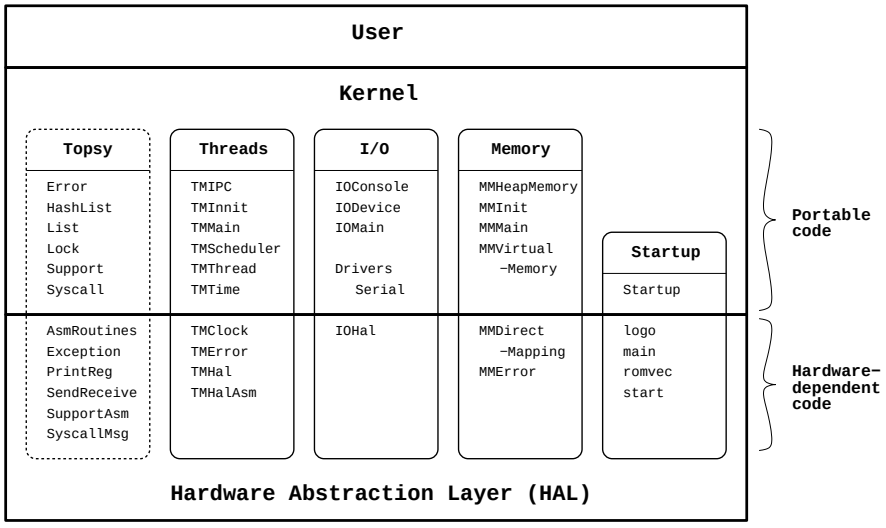


Figure 2.8: Modular structure of Topsy. The boxes named `Threads`, `I/O` and `Memory` are the main Topsy modules, while the dotted Topsy-box can be seen as a collection of routines used by the other kernel components. The `Startup`-box contains the routines involved only during system startup.

Fig. 2.8 gives an overview about the portable part of Topsy and the files related to this work.

Chapter 3

Results

3.1 Startup

This section will present the boot sequence of the Topsy kernel on the xcopilot emulator, starting from the load of the kernel and ending to the call of the portable `topsyMain()` function.

The chapter will also comprise the creation of the logo displayed on the LCD.

3.1.1 Loading the kernel

The xcopilot emulator, discussed in 2.1.2, needs "basic" parameters to start (for example the name of the kernel to load) while other parameters are optional.
In order to simplify the setup of the emulators for the correct load and run of Topsy, a little shell-script has been created and placed in the main Topsy directory with the name **xc.sh**. The script is invoked by passing, as first and unique parameter the name of the kernel image, in this case kernel.

The first thing **xc.sh** does, is to delete old memory dumps generated previously by the emulator (files pilot.ram and pilot.scratch), it loads then the specified kernel and cleans the console once the xcopilot ends. This last step is needed because of the "dirty" output generated on the console by the emulator itself.
The optional parameters embedded into the script take care to double the dimension of the graphical interface of the emulator (`-double`) and to avoid the use of the X-Window shared memory (`-noxshm`). After some hundreds consecutive runs of the emulator, a memory leak has been noticed ("shmget: No space left on device") and the graphical system had to be shut down and restarted. It is still not clear if the problem is related to xcopilot or to the version 3.3.6 of X-Window .
The parameter `-ramsize 4096` is used to set the dimension of the RAM to 4MB (the value is expressed in Kbytes), but it is not absolutely necessary because it reflects the default value used by xcopilot.
A very important parameter is the location of the datadir, it must be set to "current directory" (`-datadir .`) in order to correctly locate the kernel-file, even if specified with the parameter `-romfile`.

The first stage: Processor setting and data copying

The first step the emulator will perform after the correct load of the kernel, is to set the value of the program counter register at the memory address of `_start`, that means on the beginning of the

assembler routine start.S.
In order to quickly recognise the start point of the kernel during the debugging phase, the word "`boot`" compares at the beginning of the code. With the purpose of avoiding the interpretation of this label as an instruction, a jump instruction is needed to automatically skip this not-instruction. This trick could seem a bit complicate at the beginning, but it resulted to be a great help during the assemblage of the kernel, thus it has not been removed.
The code of start.S is well documented, it makes no sense to discuss it deeply here, so only a short description of the main functions will follow. Five are the main things this assembler-code does before the memory configuration (second stage):

1. It sets some processor-specific registers, for example it turns off the watchdog. Some registers are memory-mapped differently in the newest MC68EZ328 processor: A rough support is included here, but still not tested.

2. It sets the serial in order to give the possibility to send immediately informations in case of errors. The transmission parameters are 9600 baud, 8 bits of data, no parity and 1 stop-bit (9600/8N1).

3. It sets the LCD dimension and address of the logo (Sec. 2.1.1). The logo is displayed on the Palm LCD.

4. It copies the chunk of kernel variables from the address given by the label placed at the end of the `.logo` section to the memory address `0x10000400`. For more informations about the memory layout, please refer to Sec. 3.2.2.

5. It copies the user data and user code to the RAM, starting at `0x10100000` and `0x10200000`. The procedure used to locate the beginning and the dimension of the user portion in the ROM is explained in Sec. 3.2.1.

The second stage: Memory configuration

The C-function `_setup()` invoked as last operation by start.S, is responsible of the setup of the memory layout.
The description of the system memory is available by the header-file MemoryLayout.h. The main task of the `__setup()` function is to set the values of the structure `segmap`, values needed to correctly configure the memory regions. Before passing the control to the `topsyMain()` routine, the second stage prompts on the console the memory division, as shown in Tab 3.1.

`kernelCodeSize`	`0x00010000`	`kernelCodeStart`	`0x10c10000`
`kernelDataSize`	`0x000e1000`	`kernelDataStart`	`0x10002c00`
`userCodeSize`	`0x00100000`	`userCodeStart`	`0x10100a6e`
`userDataSize`	`0x00200000`	`userDataStart`	`0x10200000`

Table 3.1: Example of output during the setup of the memory layout. The values reflect the description on Appendix A

More informations about the layout of the memory can be found at 3.2.2.

3.1.2 The logo

Originally the logo was displayed on the screen to show up the boot process, it was a sort of alarm-bell in case of boot failure. The logo consists in a 160x160 pixel image with 1bit colour depth, in the future it could be possible to use four or sixteen-level gray scale according to the palm model. Please refer to [4] for more informations about the LCD controller of the MC68328.

The generation of a suitable logo is quite easy: It could be painted using any painting program (in this work The Gimp 1.1.24 was used) that gives the possibility to export the picture in the Windows Bitmap format. This format is used for its simplicity, even if it stores the images "bottom up": It is thus necessary to flip the image before saving it.
The colour depth of the image must be set to one bit (or "black and white", depending on the notation used by the painting tool) , with the background colour "black".
Fig. 3.1 shows an example of how the the logo used in this work looks in the painting program and on the emulator display.

Figure 3.1: Example of the painted logo (left) and the displayed one (right). Because of the Windows Bitmap format, the picture has to be flipped upside-down. Note that the white colour will be interpreted as black by the Palm.

It is still not possible to directly put the saved picture onto the kernel code, it is necessary to transform it into a suitable format. The logo.c file is simply a sequence of bytes values encapsulated into the `asm("...")` notation. In order to transform the logo from the .bmp format to .c representation, a little shell script named logo.sh has been written and placed in the directory where logo.c will reside. The script accepts as input argument the name of the picture previously saved, and generates the file named logo.c. To perform the creation of the C-source, the script needs the **hex** utility to dump the logo in CP/M-like hex format, and **awk** to process it.

Unfortunately, the picture saved in BMP-format could result not to be 160bits-aligned, generating thus a left or right-shift of the logo on the emulator display (160bits is the length of a line on the LCD). Moreover, the not-alignment leads to problems during the generation of the C-source and consequently the last 16Bytes of the file (reflecting the first 128 bits of the picture) have to be overwritten with zero-values ("white").

3.2 Memory

This section will discuss the layout of the memory by running Topsy on xcopilot.
The emulator offers a write-protected memory-area (ROM) with a dimension of 512Kbyte that reflects the flash-ROM of a real Palm.

The kernel code and the displayed logo reside in that location, while the kernel data, user code and user data are copied from ROM to the RAM during the early boot stage (See 3.1.1). Even if the latest models of Palm offer up to 8MB of RAM, for Topsy, a model with 4MB resulted to be sufficent.

The layout may vary using other emulators (for example Pose) or on a real Palm, further informations are needed in order to port Topsy on such devices. The required modifications are minimal and located only in few files.

3.2.1 The `kernel` file

The purpose of the **auto.sh** script placed the Topsy main directory is to automatise the task of the kernel creation: It cleans old files, it compiles the new kernel object-file and it dumps a suitable one.

The kernel file needed by xcopilot is generated starting from the kernel.out and user.out files that result from the compilation (Fig. 3.2). In order to produce the file needed by the emulator, the **objcopy** utility will be used. The GNU utility **m68k-coff-objcopy** is invoked with the purpose of essentially produce a memory dump of the contents of the input object file. Please refer to [33] for more informations about the copy process from an object file to another. The last operation performed by the script is to use the **cat** command to produce an unique kernel file loadable by the emulator.

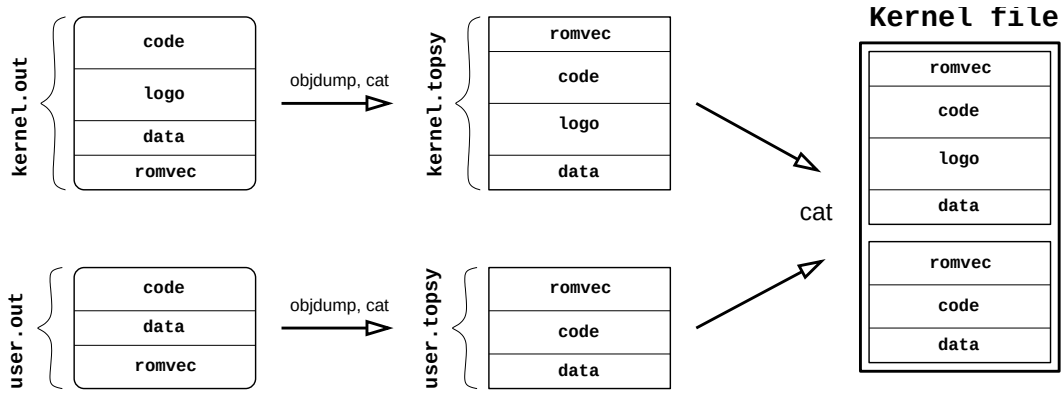


Figure 3.2: Schematic representation of the kernel creation. The script `auto.sh` generates a suitable kernel file by using **objcopy** and the **cat** utilities.

kernel.out

It is the result of the compilation of the Topsy's kernel. It consists of three parts that will be extracted by **m68k-coff-objcopy**, saved as files and and re-arranged using **cat** in order to produce the kernel.topsy file (Fig. 3.2):

1. kernel.romvec: Reflects the file romvec.c in the Startup/palm directory. It has a fixed dimension of 65Kbytes and contains informations about the "card", for example name and version.

Further informations can be found in the comments of the file itself.
The most important part of this section are the first 8bytes: They reflect the starting stack pointer (`%sp`) and the starting program counter (`%pc`) values the emulator will set once the kernel is loaded. While the correct value of the program counter can be easily determined by using the value of `_start` described in Sec. 3.1.1, the value of the stack pointer depends of the dimension of the RAM and has to

2. kernel.code: Contains the `.code` and the `.logo` sections.
   The kernel `.code` in this case has a dimension of about 25Kbytes and contains the kernel functions. Note that the code will be executed directly from the ROM. The `.logo` section is the picture shown on the LCD display and its dimension reflects the one of the display: 160x160 pixels at 1bit colour depth are 3200bytes, that means a little more than 3Kbytes. The logo file, logo.c can easily be created starting from a BMP file using the **logo.sh** utility.
   More informations about the creation of the logo can be found in Sec. 3.1.2

3. kernel.data: The last section contains the initialised and uninitialised variables used by the kernel (`.data`, `.bss` and `COMMON`). During the kernel boot-process these variables are copied in the RAM, starting from the location `0x10000400`. In order to find the boundaries of the data, the labels `__logo_end` and `__rom_dataend` are used as start and endpoint of the section. More informations about the kernel variables can be found in Sec. 3.1.1.

user.out

It contains the user part of Topsy, and it consists of three parts:

1. user.romvec: It reflects the file `head.c` and contains informations about the layout of the user portion of Topsy. The first 4 bytes are the dimension of the user code, the next 4 bytes are the address of the `main()` routine in user space (the shell) and the last 4 bytes are the dimension of the user-data. These values are needed during the setup (Sec. 3.1.1) in order to copy user-data and user-code from the ROM to the right place in the RAM. The kernel knows that these 12 bytes are located just at the end of its data portion.

2. user.code: Differently from the kernel code, the user code is copied in the RAM and executed from there. The kernel code, in the ROM, begins where the `__rom_dataend` ends, plus the (fixed) dimension of the user.romvec section. The dimension of the code is present in the user.romvec section (label `__ucode_size`).

3. user.data: The user data is copied to the RAM, starting at `0x10200000`. The start address, in the ROM, is the end of the user code and the dimension is written in user.romvec (label `__udata_size`).

An advantage of splitting the kernel and the user portions, is that the generated files can be easily examined during the early development stage using the **hex** utility.

3.2.2 Memory layout

As explained in the previous section, the first operation the emulator does, is to read the first 8bytes placed on the beginning of the kernel file and to assign to the stack pointer the first 4bytes and to the program counter the last 4bytes. The execution of the code then starts from the current value of `%pc`. The code will be executed directly from the ROM, even if speed losses are expected. The advantage

is that this memory segment is set as read-only and during development stage it is possible to detect invalid accesses on this area caused by bugged low-level code.
The stack pointer will obviously set between `0x10000000` (begin of RAM) and `0x10400000` (end of 4MB RAM). The assignment of memory portions to the operating system's components is described in two places: In the linker scripts link.palm.lnk (kernel), ulink.palm.lnk (user) and in the file MemoryLayout.h.

link.palm.lnk

Because of the lack of a clear notation, as *output-section* is to be intended one of the `.code`, `.data`, `.logo` or `.romvec` sections present in the kernel.out file shown in Fig. 3.2. As *sections* are to be intended code portions like `.text` (the executable code) or `.bss`.
The linker script assigns to each output-section one or more sections and determines where each output-section resides on the memory.

Four are the named-sections defined by the linker script:

- The `.code` output-section, starting at `0x10c10000`, contains all the executable code, that means the `*(.text)` section. At the end of the output-section, a label named `__code_end` is placed in order to recognise the end of the code.
- The `.logo` output-section starts at `__code_end`, that means where `.code` ends: Thus, is not necessary to define in advice a fixed dimension of the kernel code. This named-section contains only the `.logo` section and presents a label placed at the beginning, named `__logo_start`. The label will be used to recognise the beginning of the picture shown on the LCD display; the appropriate register is set on start.S, as explained in Sec. 3.1.1. More informations about the logo can be found at Sec. 3.1.2.
- The `.data` output-section is placed in the kernel file after the `.logo` section, but in the emulator memory its position is on the RAM, at the address `0x10000400`. This output-section contains the sections `*(.data)`, `*(.bss)` and `*(COMMON)`. A label, named `__rom_dataend` marks the end of this section.
- The last output-section, `.romvec`, starts at the memory address `0x10c00000`, contains the card-informations and the values of `%pc` and `%sp`.

ulink.palm.lnk

This is the linker script for the user part of Topsy. It consists of three output-sections, with names very similar to those of the kernel:

- The `.code` output-section starts at `0x10100000` plus the dimension of the `.romvec` section (described below). It contains all the user-code (that means all the `*(.text)` sections) and at its end there is a label (`__ucode_size`) that reflects the dimension.
- The `.data` output-section contains the `*(.data)`, `*(.bss)` and `*(COMMON)` sections and is placed in the RAM starting from `0x10200000`. Placed at its end, the label `__udata_size` contains its dimension.
- The last output-section, `.romvec`, starts at `0x10100000` and contains the value of the labels `__ucode_size`, `main` (first user-function started by the kernel, in this case the shell) and `__udata_size`, described in Sec. 3.2.1.

MemoryLayout.h

This file centralises the values describing the memory layout of Topsy for the xcopilot emulator (Fig. 3.3 and Chap. A). The values are declared using the C "`#define`" directive and will be read during the early boot stage, as explained in Sec. 3.1.1.

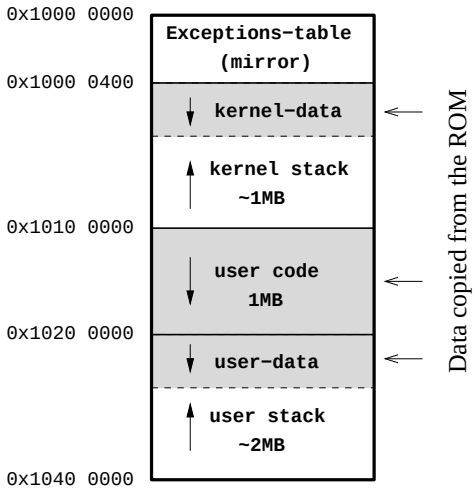


Figure 3.3: RAM layout for Topsy using the xcopilot emulator. The filled portions contain data copied from the ROM. The **kernel-data** box contains the kernel's `.data` output-section, the **user-code** box contains the user's `.code` plus `.romvec` section, and the and **user-data** box contains the `.data` output-section.

The utilisable read/write RAM has dimension of 4MB; the first 1024 bytes are a mirror of the 256 interrupts addresses (each one of length 4bytes) located at `0x0000000`. Starting from `0x10000400` kernel variables are located (section `.data` described previously). At the moment, the dimension of the kernel variables is about 5Kbytes.

Starting where the kernel-data chunk ends, and ending at `0x10100000`, quite 1Mbyte memory is reserved for kernel data: That means that, at the beginning, the value of `%sp` has to be set to the end of this chunk (the stack grows from the "bottom" to the "top") minus 4bytes.

1Mbyte of memory has been reserved for the user code and the last 2Mbyte are dedicated for the user data. A possible stack overflow of user data with possible damage of kernel informations, should be avoided by the position of the chunk itself: By overwriting user-code, the malicious thread should stop itself in time.

The processor of Palm, the MC68328, offers the possibility to specify up to four different classes of devices/memory using the *chip-selects* register. Thus, it is possible to set the kernel portion of RAM as read-only during execution of user-threads with the purpose to avoid illegal access to kernel portions (the memory-mapped registers are protected from illegal access in user-mode). Further investigations are required in this direction to determine the performance loss of such method.

Topsy will further divide the memory into regions. After some tests, the granularity of regions has been set to 1Kbyte ("`#define PAGEBITS 10`" and "`#define LOGICALPAGEBITS 10`"): This value is a good compromise for devices with limited resources like Palm.

Memory Mapped registers and interrupts

As already explained in Sec. 2.1.1, the registers are memory-mapped starting from `0xfffff000`. An exhaustive description of the register can be found on Sec. 3.4.4. Refer to [4] for further informations about the role of the registers.

The xcopilot puts a mirror of the vector table at the beginning of the RAM, that means starting from `0x10000000`, as shown in Fig. 3.3. Interrupt handling is explained in Sec. 2.1.1.

3.3 Threads

The threads module in Topsy is responsable for threads initialisation and management. This chapter will concentrate on the interrupt handling and the mechanism used for saving and restoring the thread context.

3.3.1 Interrupts handling

The mechanism used for interrupt handling has already been explained in Sec. 2.1.1. Main purpose of this section is to explain the handling routines related to the message passing mechanism and to unexpected situations (“exceptions”).

Exception vector assignment

The Interrupt Vector Register (`IVR`) is an 8bit vector mapped at the address `0xfffff300`. The vector number provided by this register can take values from 0 to 255, that means the MC68328 supports 256 exceptions.
In this work, only two routines will be used to deal with interrupts. The `syscallHandler` is used for the `trap` instruction, while `dummyExceptionHandler` is used for the remaining interrupts (Fig. 3.4). More handling routines (designed to serve, for example, timer interrupt or I/O operations), can be installed using `tmInstallExceptionCode()`.

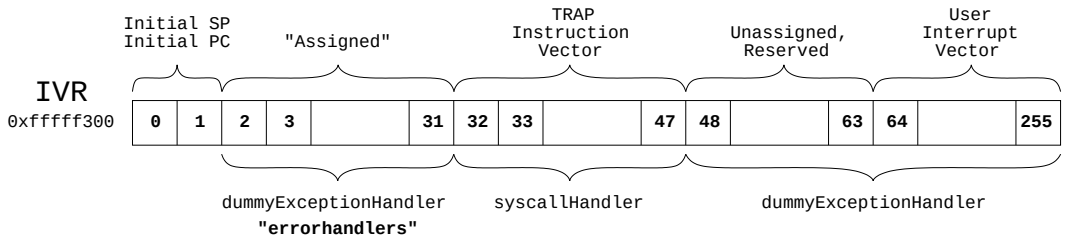


Figure 3.4: The exception generated by the “`trap #n`” instruction use vector number 32+n and are handled by the `syscallHandler` routine, while all other interrupts, on the beginning, are assigned to `dummyExceptionHandler`. Vector numbers from 2 to 31 are reserved for future enhancements or assigned for specific error situations (bus error, divide-by-zero, etc.).

Exception and interrupt handling

The installation of interrupt handling is performed by `initBasicExceptions()` during the startup phase. First of all, `tmInstallExceptionCode()` is called in order to install the 16 handlers (`syscallHandler()`) for the `trap` instructions (`trap 0-trap 15`). Actually, only the first two handlers are used for message passing. The next step is the installation of exception handlers: Because there's no distinction between interrupts and exceptions, `tmSetExceptionHandler()` installs `dummyExceptionHandler()` for all the 255 (`MAXNBOFEXCEPTIONS`) possible interrupts. The previously installed handlers are not overwritten.`tmSetInterruptHandler` is not executed, because of the use of a unified model without special interrupt table (`MAXNBOFINTERRUPTS` is equal to 0).
`tmInstallErrorHandlers()` takes care to install handling routines designed for system errors, such as attempt to access privileged resources or divide-by-zero. These routines are implemented in `TMError.c()` (Tab. 3.2).

Vector number	Assignment	C-function
2	Bus Error	`tmBusError()`
3	Address Error	`tmAddrError()`
4	Illegal Instruction	`tmIllInstructionError()`
5	Divide-by-Zero	`tmZeroDivideError()`
6	CHK Instruction	`tmRegisterBound()`
7	TRAPV Instruction	`tmStackOverflowError()`
8	Privilege Violation	`tmReservedInstructionError()`
10	Unimplemented A-Line Opcode	`tmIllInstructionError()`
11	Unimplemented F-Line Opcode	`tmIllInstructionError()`

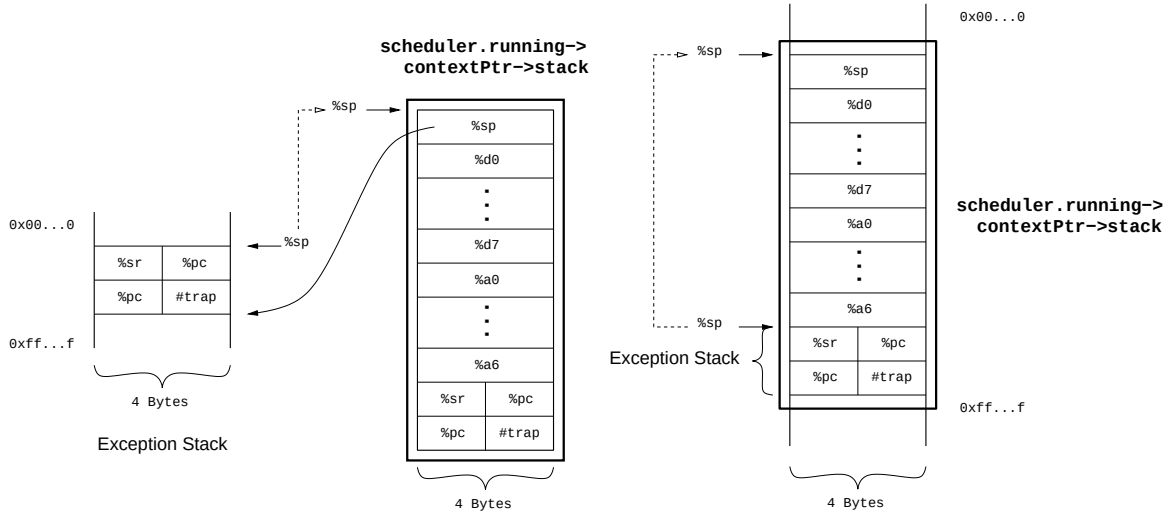
Table 3.2: Error exception assignment. Each C-function puts on the console the type of error and the context of the thread (function `tmError`).

Unimplemented error exception 0 and 1 are reserved for the initial values of stack pointer and program counter ("Reset"). The vectors 12-23 are reserved for future enhancements by Motorola, numbers 25 to 31 are assigned to 7 IRQ ("Interrupt Autovector") in increasing priority. The number 24 ("Spurious Interrupt") is taken when there is a bus error during interrupt processing: in Topsy interrupts are disabled during exception handling, thus it is not used. The vector number 9 is assigned to the trace interrupt, refer to Sec. 4.2.1 for a possible future use. A list of exceptions is implemented in Topsy/palm/Exception.h.
Explanation of system exceptions is beyond the aim of this section, refer to [4] for more informations.

`syscallHandler()`

It is the routine used in case of a system call, that means it is used to perform a "send" (SEND) or a "receive" (RECV) operation. Unfortunately, the `trap` instruction for the MC68EC000 core doesn't write on the stack the value of the interrupt that caused the exception, like other processors of the same family do; it pushes only the value of the program counter (`%pc`) and of the status register (`%sr`). Thus, it is necessary to write this value before the instruction and to remove it once returning from the exception (Fig. 3.6).
The assembler routine `syscallHandler` uses the registers `%a0`, `%d0` and `%d1` as parameters. The

mean of these parameters depends in case of a send or a receive operation, as shown in Tab. 3.4 and Tab. 3.5. First of all, the routine turns into supervisor mode, disables the trace and sets the interrupt priority mask to 111 by manipulating the status register described in Fig. 2.2. By testing the value of the status register pushed on the stack by the `trap` instruction, it determines if the thread that generated the system call was running in supervisor or in user mode. In case of a kernel thread (supervisor mode), the values of the registers (`%d0`-`%d7` and `%a0`-`%d6`), the whole exception stack (`%pc` and `%sr`) and the value of `%sp` before the `trap` instruction are saved in the appropriate structure[1]. The value of the system call is copied too, but only for debugging purpose.
The stack is switched: From now on it will grow starting from the address of the structure, from the "top" of it. The only difference in case of an user thread, is that the values are saved on the stack and the address of the structure is switched. Fig. 3.5 shows both cases.
Next task performed by `syscallHandler`, is to increment the number of threads present in the kernel. Then the C-routine `handle()`, responsible for message dispatching, is called. By returning from this routine, the last task performed by `syscallHandler` is to push on the stack the value of `scheduler.running` as parameter for `restoreContext()` and to jump, without return, to that routine.



(a) Kernel thread.

(b) User thread.

Figure 3.5: In case of kernel thread, the context is saved in the appropriate structure and `%sp` is switched to point on the top of it. In case of user thread, the context is saved on the stack, and the structure is switched to point on the top of it. In both cases, the value of `%sp` saved on the structure, points to the base of the stack before the `trap` instruction (not shown on user thread).

`dummyExceptionHandler()`

The task of this routine is to take care of all the exceptions that don't are assigned to a specific handler. This is the case of the exceptions with vector number in the range from 48 to 255, although further handler (for example for a timer interrupt with vector number 65) can be installed here.

[1] `scheduler.running->contextPtr->stack`

3.3.2 Threads management

When the system call `tmMsgSend` or `tmMsgRevc` is invoked, the running thread has to be suspended, the message has to be dispatched to the right thread and, depending of the scheduler decision, a new one has to be restored.
As explained in Sec. 3.3.1, before the routine responsible for saving the context is called, a value reflecting the system call has to be written on the stack: The value "0" means a SEND operation, while the value "1" means RECV. These numbers are passed to the portable `msgDispatcher()` routine by `handle()`, present in TMHal.c.

`restoreContext`

The C-routine `restoreContext()`, which is present in TMHal.c, is responsible of calling the right assembler routine designed to restore an user or a kernel context. Using the value of the status register (`%sr`), saved by `syscallHandler` in the thread-structure, either `restoreSuper` or `restoreUser` are called. The `restoreSuper` assembler routine is shown in Tab. /reftab:RestoreSuper.

The assembler routine `restoreSuper` is implemented in TMHalAsm.S and is responsible for restoring the context of a kernel thread. Using the informations present in the thread structure, the situation after the `trap` instruction is restored. The exception stack *without* the system call number is restored and the `rte` instruction is invoked in order to return to the situation before the `trap` (Fig. 3.6).

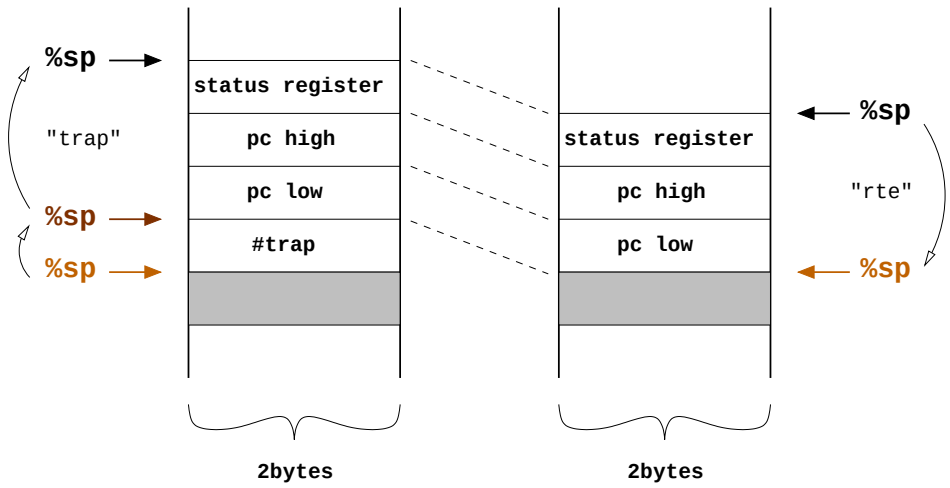


Figure 3.6: Before the `trap` instruction, the value of the system call has to be pushed on the stack. The `rte` instruction expects on the stack the values pushed previously by `trap` (status register and program counter), thus the system call number doesn't have to be restored.

`restoreUser` is similar, but in this case the exception stack is already present on the user-stack. The only task is to restore the value of the registers and to remove the system call number.

Both routines need as parameter a pointer to the thread structure to restore. This parameter is 4bytes long, and, as explained in Sec. 2.2.3, it is available at the address `4(%sp)`.

```
move.l 4(%sp), %a0                /*  %a0 is "stack"          */
move.l (%a0), %sp                 /*  Restore %sp             */
move.l 66(%a0), -(%sp)            /*  Copy %pc                */
move.w 64(%a0), -(%sp)            /*  Copy %sr                */
addq.l #4, %a0                    /*  Move %a0 to "%d0"       */
movem.l (%a0)+, %d0-%d7/%a0-%a6   /*  Pop saved registers     */
movem.l -24(%a0), %a0             /*  Restore original %a0    */
rte                               /*  Return from exception   */
```

Table 3.3: Implementation of `restoreSuper`. The exception stack generated by the `trap` instruction is copied on the stack, the value of the registers are restored and the `rte` instruction is invoked.

Build of a new thread

During the build of a new thread, performed by `threadBuild()` present in TMThread.c, the context of the new thread has to be created as ready to be started.
The routine `tmSetStackPointer()`, implemented in **TMHal.c**, takes care to reserve 8bytes on the stack for the address of the exit code (4bytes) and for the argument passed to the thread (4bytes). The routine `tmSetReturnAddress()` writes the address of the exit code at `(%sp)` and `tmSetArgument0()` writes the value of the parameter passed to the thread at `4(%sp)`. This is needed in order to respect the GCC calling convention, as explained in Sec. 2.2.3 and shown in Fig. 2.7.

3.4 Topsy

The **Topsy** module can be seen as a collection of routines used by various kernel components, it has not a precise task to absolve, as the modules **Memory**, **Threads** and **I/O** have.

3.4.1 System-calls

The file SyscallMsg.c contains the the two syscall-routines used to send and receive messages: `tmMsgSend()` and `tmMsgRecv()`. Actually, these routines are used only to display some debugging information on the console and to call the main routines, `MsgSendAsm` and `MsgRecvAsm`, implemented in assembler (file SendReceive.S)[2].

`MsgSendAsm`

The routine needs as parameters a pointer to the message to send (`msgPtr`) and the identification number of the destination thread (`to`). These values, available on the stack at the location `8(%sp)` and `4(%sp)`, are copied into the registers `%a0` and `%d0`, as shown in Tab. 3.4. Before performing the system call, `MsgSendAsm` copies the destination thread-id (`to`) into the `from` field of the message and pushes the systemcall value on the stack (in this case, the 2Bytes-long value "`0`").

[2] In the latest version of this work, the assembler routines are called directly, and thus they have been renamed to `MsgSend` and `MsgRecv`

Returning from the exception, the register `%d0` contains the return-value of type `SyscallError` indicating the status of the send operation (`TM_MSGSENDOK` or `TM_MSGSENDFAILED`).

```
move.l 4(%sp),%d0  /*  %d0 := to            */
move.l 8(%sp),%a0  /*  %a0 := msgPtr        */
move.l %d0, (%a0)  /*  msgPtr->from := to   */
move.w #0, -(%sp)  /*  SEND syscall         */
trap #0            /*  call syscallHandler  */
rts                /*  Return               */
```

Table 3.4: Implementation of `MsgSendAsm`

`MsgRecvAsm`

Like `MsgSendAsm`, this routine has to assemble the message before performing the `trap` instruction: The `from` field has to contain the identifier of the message sender and `id` an identification value for the type of message. The value pushed on the stack to identify the syscall in this case is "`1`".
After the `trap` instruction, it is possible to return to the calling routine (`rts`). The register `%d0` contains a value indicating the status of the operation: `TM_MSGRECVOK` in case of a success, `TM_MSGRECVFAILED` otherwise. The implementation of `MsgRecvAsm` is shown in Tab. 3.5.

```
movea.l %sp@(4), %a1   /*  %a1 := from             */
move.l %sp@(8), %d0    /*  %d0 := msgId            */
movea.l %sp@(12), %a0  /*  %a0 := msgPtr           */
move.l %sp@(16), %d1   /*  %d1 := timeOut          */
move.l %a1@, %a0@      /*  msgPtr->from := *from   */
move.l %d0, %a0@(4)    /*  msgPtr->id := msgId     */
move.w #1, -(%sp)      /*  RECV syscall            */
trap #1                /*  call syscallHandler     */
rts                    /*  Return                  */
```

Table 3.5: Implementation of `MsgRecvAsm`

3.4.2 A small math-library: AsmRoutines.S

This file implements some mathematical operations using long integers (32bits). Even if the support for these operations is present in **newlib** (Sec. 2.2), it has been decided to write a very thin mathematical library in order to keep the Topsy's kernel smaller (these routines are needed by the user-part of Topsy too). The functions implemented are:

- `__divsi3`: Used to divide two long integers (variables of type `long`), or to find the remainder of the division of such data. It uses `__udivsi3`.
- `__udivsi3`: Used to divide two long *unsigned* integers.

- `__modsi3`: Remainder in division of one long integer by another. It uses the routines `__divsi3` and `__mulsi3`.
- `__umodsi3`: Remainder in division of two *unsigned* integers. It needs `__udivsi3` and `__mulsi3`.
- `__mulsi3`: It is necessary to multiply two long integers.

The implementation in assembler of these routines has been taken directly from the compiled μCLinux kernel, using the **m68k-coff-objdump** utility.

3.4.3 Assembler support: SupportAsm.c

In this file some inline assembler routines are implemented. They were written with the purpose to help the debugging phase. For example, it is possible to read the value of the stack pointer, to set and to read the register `%a0`-`%a6` and `%d0`-`%d7` and to read the value of the Interrupt Vector Register (see Fig. 2.4). The routine `testAndSet` is implemented here, too.

3.4.4 MC68328 registers description: cpu.h

The file `cpu.h` contains a description of the memory-mapped register of the MC68328-Dragonball processor. Actually, these definitions are not extensively used, but they can result to be very comfortable in a wider Palm implementation of Topsy.

3.5 Input/Output (IO)

The Input/Output (I/O) subsystem of Topsy provides a framework for writing and installing hardware drivers. Some low-level routines are available with the purpose to send data on the serial port during the initialisation-phase of Topsy (debugging informations). A more complex and flexible serial interface is implemented in oder to interact with the user.

3.5.1 IOConsole

The file **IOConsole.c** contains very simple console output routine, used at startup, on catastrophic events or for debugging:

- `ioConsolePutString(const char* s)`: It uses the `ioConsolePutChar()` routine to put a whole string on the console.
- `ioConsolePutInt(long x)`: It writes an integer (32 bits).
- `ioConsolePutHexInt(unsigned long x)`: It is similar to `ioConsolePutInt()`, but the written number is converted to hexadecimal base.

All these routines are based on `ioConsolePutChar()`, implemented in **IOHal.c**. This routines simply calls the hardware-dependent `ioSerialPutChar()` one: The reason is that xcopilot binds automatically the serial to the console that started the emulator. `ioSerialPutChar()` is a very short inline-assembler routine that writes a character (byte) on the UART transmitter register (`UTX`).

This register, mapped at the address `0xfffff906` and 16bit long, contains data to be transmitted and reports the status of the operation. Thus, the 8bit data has to be written on the second half of `UTX`, more precisely at the address `0xfffff907`:

```
void ioSerialPutChar(char c)
{
  asm ("moveb %0, 0xfffff907"
       :: "r" (c)
       );
}
```

Note that, even if `ioConsolePutString()` puts a CR/LF sequence at the end of each string (`\r\n`), a further sequence is needed in order to correctly terminate a line and start a new one: Each string passed to `ioConsolePutString()` has to end with "`\r\n`".

3.5.2 The driver

The files Serial.c and Serial.h present in the Drivers/palm directory, offer the access to the UART for serial communication with external devices. The functions `Serial_init()`, `Serial_read()`, `Serial_write()` and `Serial_close()` are accessible via a pointer to a structure describing the device (`iODevice`).

The file Serial.c, located in `Drivers/palm`, is the implementation of the functionalities offered by the serial device of the MC68328:

- `Serial_init`: Initialisation of the serial, as done during the startup (Sec. 3.1.2). The serial is initialised at the speed of 9600 baud with 8bits data-length, 1bit stop and no parity; CTS (Clear To Send) is ignored.
- `Serial_read`: It reads a specified amount of bytes from the UART receiver register (`URX`, mapped at `0xfffff904`). The register is 16bit long, the first half describes the status of the serial. That means that the bytes are read from the second half, starting at `0xfffff905`. After each read, a write to the UART transmitter register (`UTX`) is performed ("echo").
- `Serial_write`: The implementation is similar to `ioSerialPutString`. It puts on the serial the content of a buffer.
- `Serial_close`: It simply returns `IO_CLOSEOK`.

Chapter 4

Discussion and outlook

With this thesis work, Topsy has been ported to the Palm Pilot platform. This is could be seen as only the beginning of a wider support of Palm, because of the potentiality of the whole project, as explained in this chapter.

4.1 Discussion

Purpose of this work was the port of the Topsy operating system to the Palm Pilot PDA based on the MC68328 processor. Main points of the work were:

1. **Port of the Topsy HAL (Hardware Abstraction Layer) under the Palm architecture**
   As starting point, the existing port for Motorola 68k [13] had to be used. Because of the release of the whole work under the Gnu Public Licence (GPL), all the tools used for the work had to be available under the same licence.

   The HAL has been successfully ported to run on the Palm processor, and the hardware independent part of Topsy hasn't be modified in any way. Moreover, the user part of Topsy has been added: not only the kernel runs on the new architecture, but even user threads can be started and rescheduled correctly. For example, after the setup of the system performed by the kernel, the `Shell`-thread is started and the serial driver is initialised: That means the switch from kernel to user mode is performed without problems. Fig. 4.1 shows Topsy running on the xcopilot emulator and the output of the shell running in user-space.

   All the tools used for the port, compiler, assembler and linker and even the emulator, are available under GPL.

2. **Input/Output**
   On the Palm, the display is used as interface between the user and the system: Input is provided by a touch-sensitive area of the screen, and output is displayed on the same device. Purpose of this work was to offer a minimal input/output using the serial or the infra-red interface.

   A driver for the serial has been developed and output provided. Unfortunately, there are still some problems related to the input: Data flows between the emulator to the user in both directions, but xcopilot doesn't seem to be able to capture the incoming bytes in the appropriate register.
   An implementation of a driver for the infra-red interface couldn't be developed because of the lack of such a device on the emulator. The similarities between the serial and the infra-red interface should reduce this part to a mere adaption-task.

(a) Topsy **(b)** Shell

Figure 4.1: Topsy running on the xcopilot emulator and the output of the shell running in user-space. If not specified, the serial output is automatically redirect by xcopilot to the console that invoked the emulator.

Using the display, some output to the user is provided by the visualisation of the logo. Because of very early configuration of the LCD during the kernel startup phase, the appearance of the picture can be treated as symptom of a correct initialisation of the system.

3. **PalmOS applications under Topsy**
   Because of the availability of a very wide choice of existing software for PalmOS, possibilities to run these applications under Topsy had to be investigated.
   Unfortunately, the lack of time avoided a deep research in this direction, but a brief discussion can be found on 4.2.2.

4.2 Outlook

The port of Topsy on Palm is only a start point for a wider use of this operating system. There are many features of the Palm platform that can be implemented in Topsy, maybe the most interesting is the use of the LCD display as Input/Output device.
Before adding new features to the Palm, a more robust development environment has to be created. Besides the software emulator used in this work, xcopilot, some hardware platforms are available. The emulator itself can be expanded in order to offer a suitable interface for debugging.
This section will give an overview of possible future enhancements of the Topsy port on Palm: Not all proposed ideas has to be implemented, but most of them can make the use and the development of

the operating system easier.

4.2.1 Debugging

The xcopilot emulator was originally designed to run the Palm operating system, thus, the debugging tools are designed to help the programmer to develop PalmOS applications.
During this work, the memory dump generated by xcopilot was almost the only way to have an overview about the status of the kernel; the use of serial output was not always possible (expecially in "critical section" such as context restoring or interrupt handling) and putting infinite loops in the middle of the code was the only way to stop its execution.

Purpose of this section is to describe some possibilities voted to turn the debugging phase into a quick and fast task and, thus, to make the implementation of new functionalities easier and less error-prone:

- **Trace:** The MC68000 processor gives the possibility to set the processor in the "trace mode" by manipulating the status register. When running in supervisor mode, it is possible to use the assembler `stop` instruction. When invoked, `stop` advances the program counter to the next instruction and stops the fetching and executing of instructions. A trace exception occurs if the "T" bit of the status register was previously set to 1 (Fig. 2.2). With this method it is possible to put breakpoints in the code and to analyse the status of the system. An interrupt handling routine, corresponding to the vector number 9 ("Trace", refer to Sec. 3.3.1), has to be implemented.

- **A patch for xcopilot:** The success of μCLinux leads to the idea to develop a patch for the xcopilot emulator to help the debug of the Linux kernel. Because of its independency from the operating system, this feature can be used to help in debugging Topsy, too. Unfortunately, the patch is still in an early development phase, and the released alpha-version has still some problems. The patched version of xcopilot and further informations can be found on [25].

- **Patching Pose:** The **P**alm**OS E**mulator is the official emulator offered by Palm Inc. for developing PalmOS applications. The interesting aspect of this emulator is the possibility to emulate even the newest models of Palm (based on the MC68EZ328), and the availability of third-parties interfaces written with the purpose of low-level debugging [35].
  Unfortunately, as the name says, Pose doesn't emulate the whole Palm hardware, it is mostly designed to emulate the native operating system. Because of the free availability of the source code, it could be possible to modify Pose in order to let it emulate a real Palm.

Besides xcopilot and, eventually, pose, there are some other hardware tools that can be used as debugging platform:

- **The MC68328ADS:** [19] Motorola offers an *Application Development System* consisting in a board with an MC68328 processor, 1MB SRAM, 1MB EPROM, a parallel and two serial interfaces, a Windows-based debugger in boot EPROM and an LCD touch panel interface.
  The **M68EZ328ADS** is a similar development system, the most remarkable difference is the MC68EZ328 processor present in the newest Palm handhelds.

- μC**Simm**: [36] It is a microcontroller module specifically built for the μCLinux operating system. It measures an inch high, with a standard 30-pin SIMM form factor. μCSimm is driven by the MC68EZ328 processor, and is equipped with 2 MB of FLASH and 8MB of DRAM. There is also a built-in LCD panel driver capable of displaying QVGA at a resolution of 320x240.

Its similarities with the Palm architecture (the original μCLinux runs on the Palm with very few modifications) make it an interesting substitute of the Motorola development board.

4.2.2 Topsy enhancements

The LCD display

At this stage, Topsy uses the serial interface to communicate with the user. That means, a Palm equipped with Topsy can hardly be used "on the road".
The LCD display of the Palm is used only to display a logo, but it can be turned in a very powerful Input/Output device: In the near future it could be possible to use the LCD display as primary output interface and the serial can be devolved for debugging purpose. As starting point for implementing a characters-based output on the screen, the framebuffer device of μCLinux can be used.
The LCD panel on the Palm provides pen input: By tapping on the screen, the x and y position is determined and an IRQ is presented to the processor. Refer to [19] for more informations.

There are different implementation of handwriting recognition programs available under GPL or similar licence. An introduction to handwriting and gesture recognition is available at [37].

- **Xscribble** [38] is an X11 application that allows a user to input characters into X11 applications, using a uni-stroke (graffiti like) alphabet. It uses the X11 test extension to allow synthesis of characters as though they had been typed on a keyboard.
  Investigation about the possibility to use Xscribble without X11 support are needed.
- **XMerlin** [39] is a simple, small footprint, single character recognition engine for X11 based web pads. The author affirms [40] XMerlin is very fast in analysing and recognising the characters: Approximatively 0.1 seconds/characters on a Pentium running at 133MHz. The soft is not-adaptive, and thus not very robust: About 83% of the characters tipped by inexperienced users were recognised, while after some training the percentage grew up to 87%
  Unfortunately, XMerlin requires Xlib, thus the possibility of an implementation on Topsy has to be investigated.
- **LibStroke** [41] is a stroke translation library. Strokes are motions of the mouse that can be interpreted by a program as a command and are used extensively in CAD programs. The very simple idea behind LibStroke should lead quickly to an implementation for Topsy; even the accuracy has proven to be quite good [42].
- **GridWrite** [43] is based on LibStroke and uses a visible grid; characters are created by moving the stylus between squares on the grid. Because of the presence of well-defined area for text and number input on the Palm, this solution could be very interesting.

PalmOS emulation

The success of PalmOS has been widely determined by the availability of many applications, and probably the end-user won't renounce to the existing software. There are three possible methods to permit the use of PalmOS applications with Topsy:

1. **Dual-boot**: The idea is to have both systems present in the Palm, and to select which one is to use. There seem to be two main ways:
   - Load the Topsy kernel into RAM and execute it there. This has the advantage of retaining PalmOS. It has the disadvantage of leaving less RAM available.

- Write the kernel into the flash and execute it in place. This approach has the advantage of maximising the use of the flash. The disadvantage is that PalmOS can't be moved to a different address space, so the space for Topsy may result to be insufficient.

In both cases, the idea is (after a reset-event) to let the program counter point to a small routine that will take care to prompt to the user a menu with the choice between booting PalmOS or Topsy.

2. **Library**: All the PalmOS specific functions are available in a library under Topsy. That means, all the calls performed by Palm applications to the Palm operating system, are absolved by Topsy. This method has the advantage to offer under Topsy a full binary compatibility (with little overhead) to all the applications developed for the Palm. This is the approach used by WindStone [44].

3. **Virtual machine**: Another possibility is to emulate the whole Palm architecture. This approach is nowaday used by **vm**ware [45], but it could hardly be implemented with satisfactory performances with such limited hardware resources.

4.2.3 Palm-related enhancements

The MC68328 processor combines a MC68EC000 processor with peripheral modules and system interface logic. In this work only few components has been used: The UART for serial input/output, the LCD controller for the logo, the enhanced real-time controller and the interrupt controller. Purpose of this section is to give an overview about future enhancements strictly related to the processor.

- **UART controller**: Besides the support of a serial (RS232) interface, the UART module offers the Infra-red (IrDA) mode. The implementation should not be difficulty (a driver for the RS232 is already present), but in order to test it, it would be necessary to have Topsy running on a real Palm.

- **Pulse-width modulator**: The pulse-width modulator (PWM) of the MC68328 provides high-quality sound generation and can also generate tones. Unfortunately, the speaker provided by the Palm has poor quality: It is adequate for alarms but will not do, for example, DTMF (Dual Tone Multiplexed Frequency) tones. It could be interesting to implement a sort of warning-tones as the common PCs do during the boot, in order to recognise, for example, unexpected situations.

- **LCD controller**: Actually, only black and white picture are displayed, but the LCD controller is capable of using up to sixteen gray levels.

- **Chip-select**: The MC68328 processor contains eight general-purpose, programmable, chip-select signals, used for memory configuration. An interesting possibility offered by chip-select registers, is to define memory portions as read-only or read/write.
  In the future, it could be possible to implement a sort of "memory protection", for example by setting the kernel memory as read-only while executing user code. The resulting overhead of such operation for each context-switch it is still not clear; further investigations are needed.

- **Power controller**: The power controller module has three modes of operation: *Normal*, *Doze* and *Sleep* that can be configured by manipulating the power control register (PCTLR).

Last word

With this thesis work, Topsy has been ported to the Palm Pilot platform. This is could be seen as only the beginning of a wider support of Palm, because of the potentiality of the whole project, as explained in this chapter.

Chapter 5

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”a piccoli passi si arriva fino in cima all’Everest !”

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Appendix A

Overview of memory layout